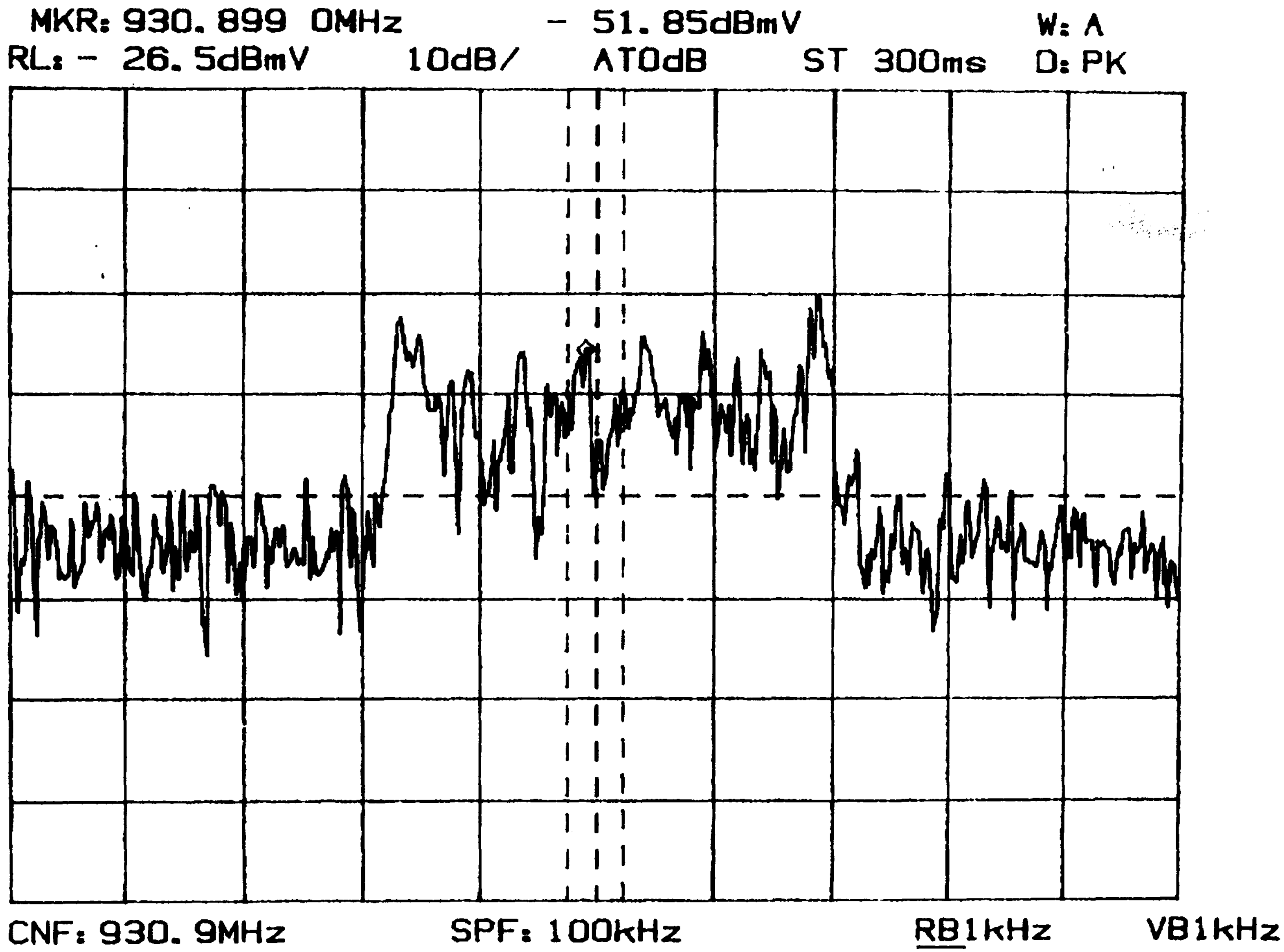


Fig. E-7
Equi-Signal Area
With Both Transmitters Approximately Equal

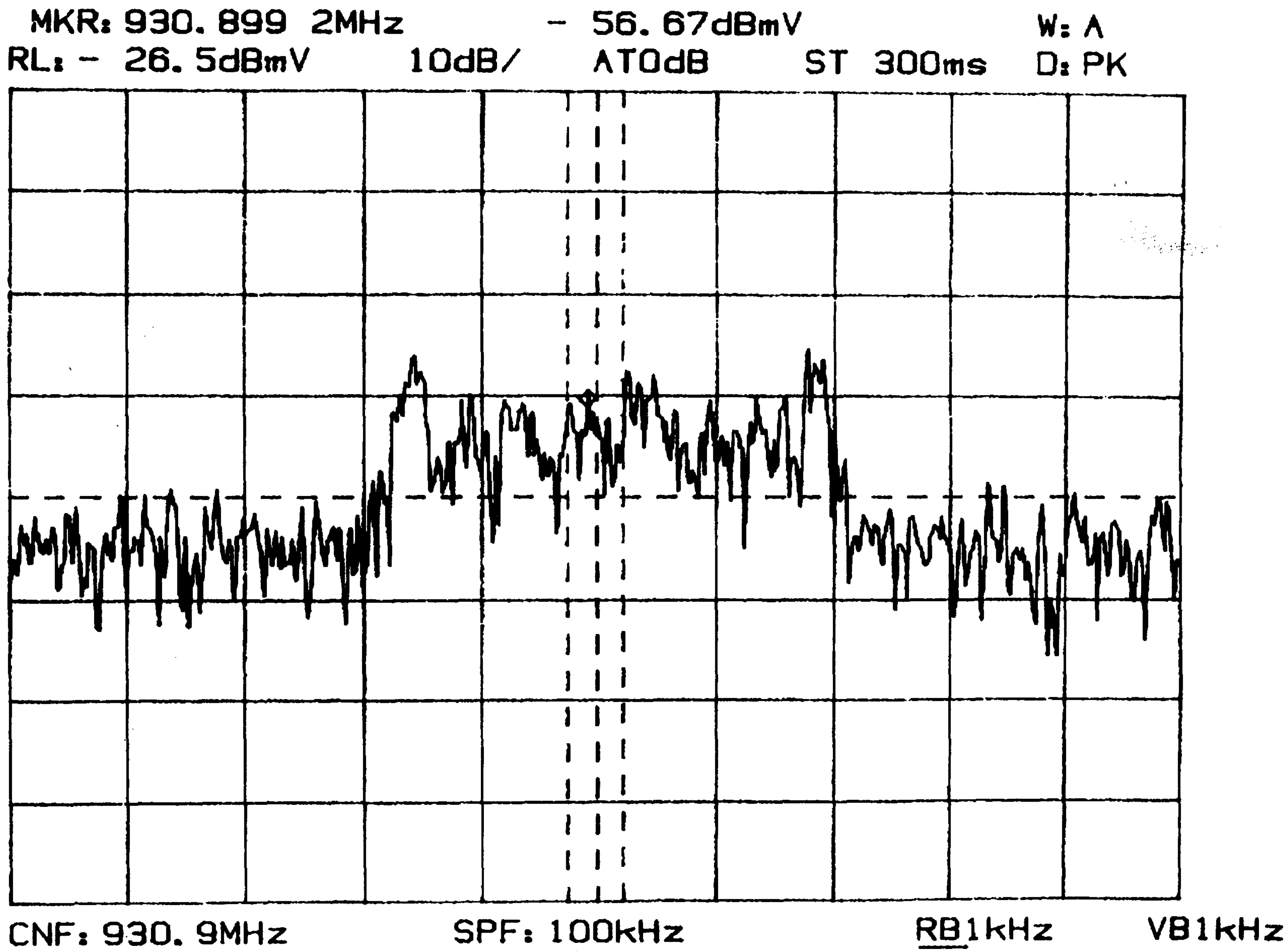


Fig. E-8
Equi-Signal Area with Transmitter
1 approximately
10 dB Stronger

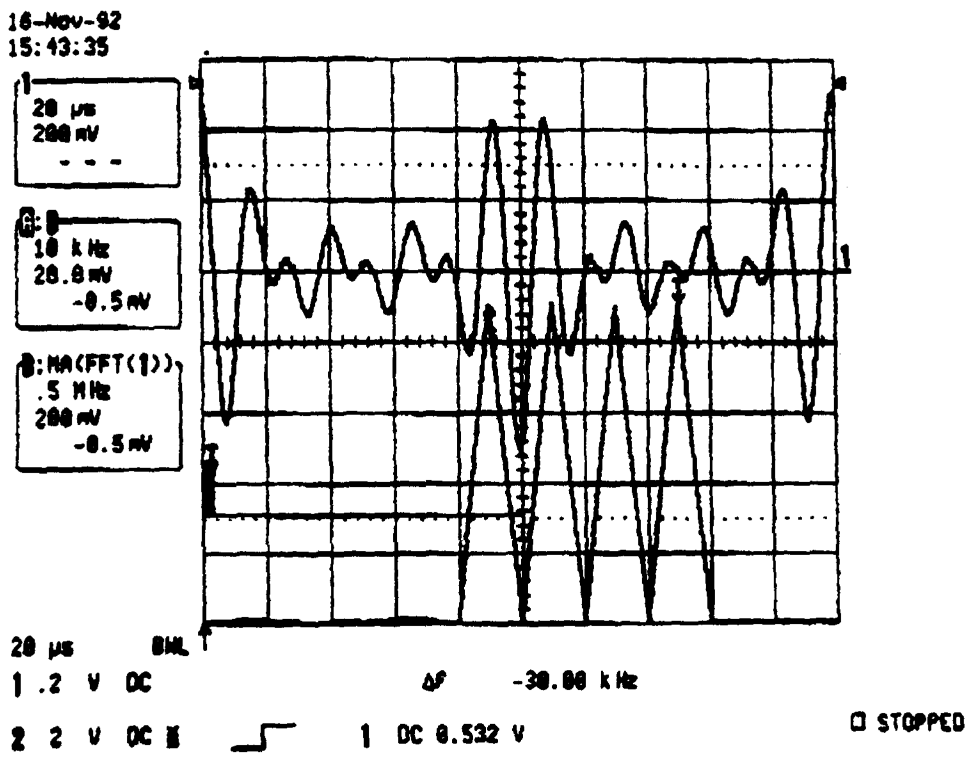


Fig. E-9
Baseband PFSK Signal
Generated in the Laboratory by the
Waveform Generator

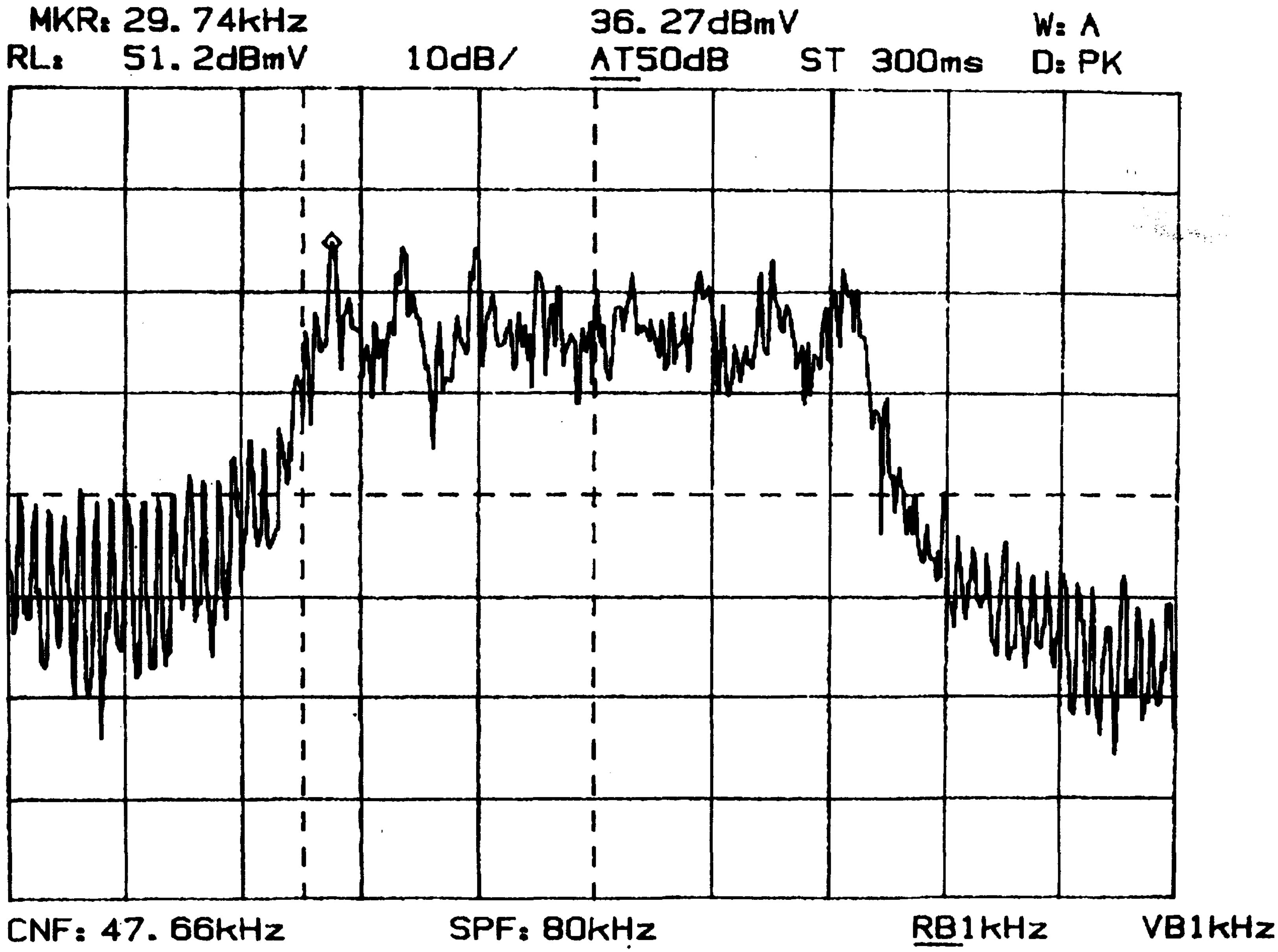


Fig. E-10
Spectrum of a Typical 16 Symbol
Long Baseband Test Sequence

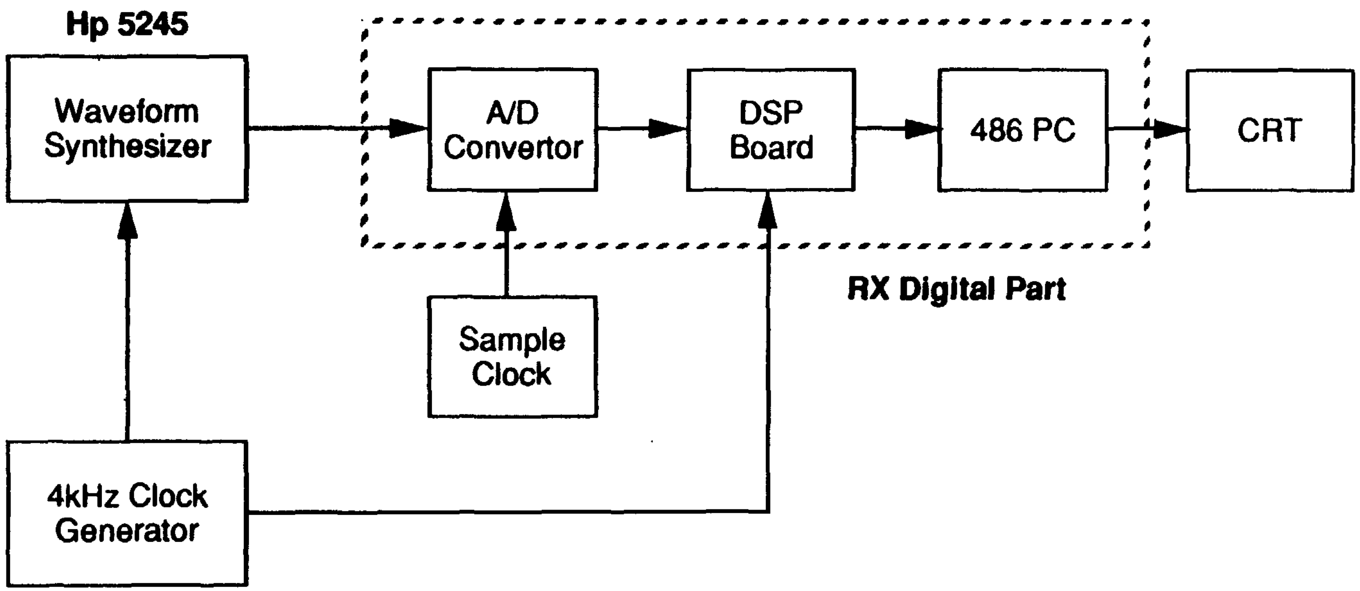


Figure E-11 Laboratory Receiver Baseband Test Set-Up

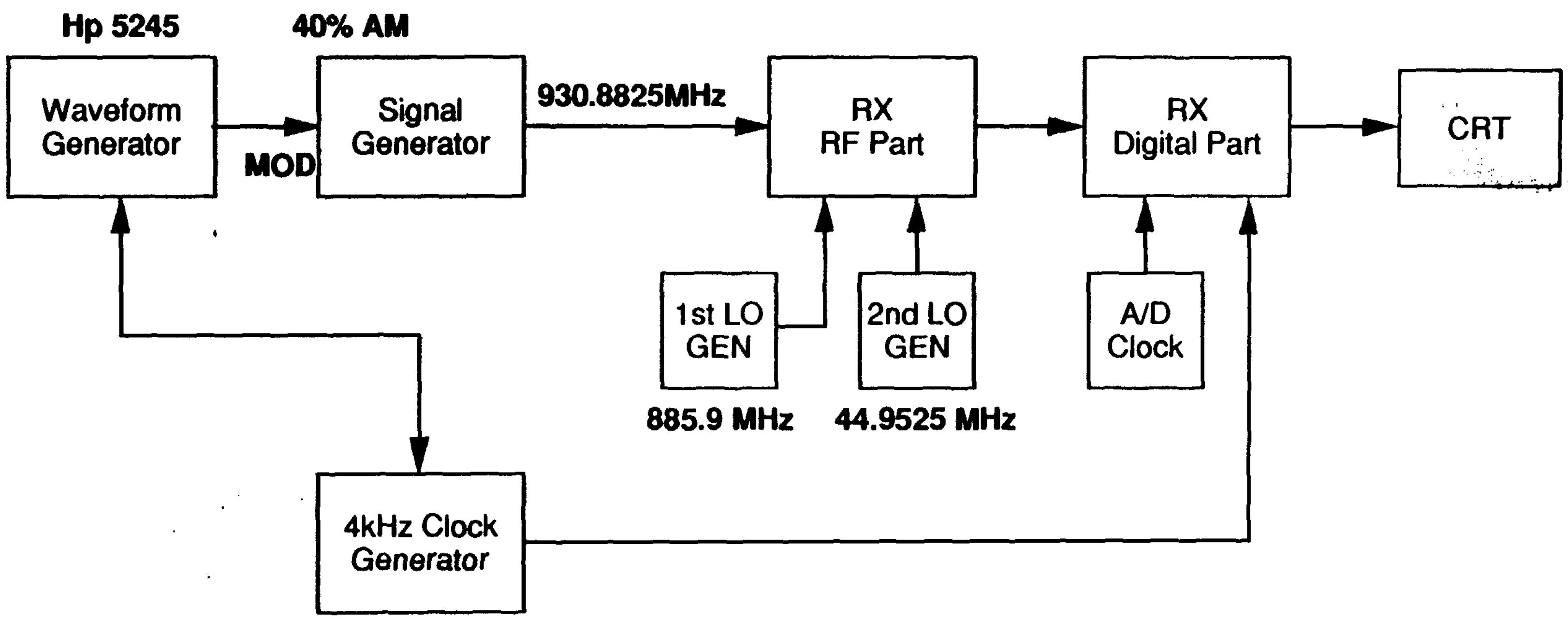


Figure E-12 Laboratory Receiver RF Test Set-Up

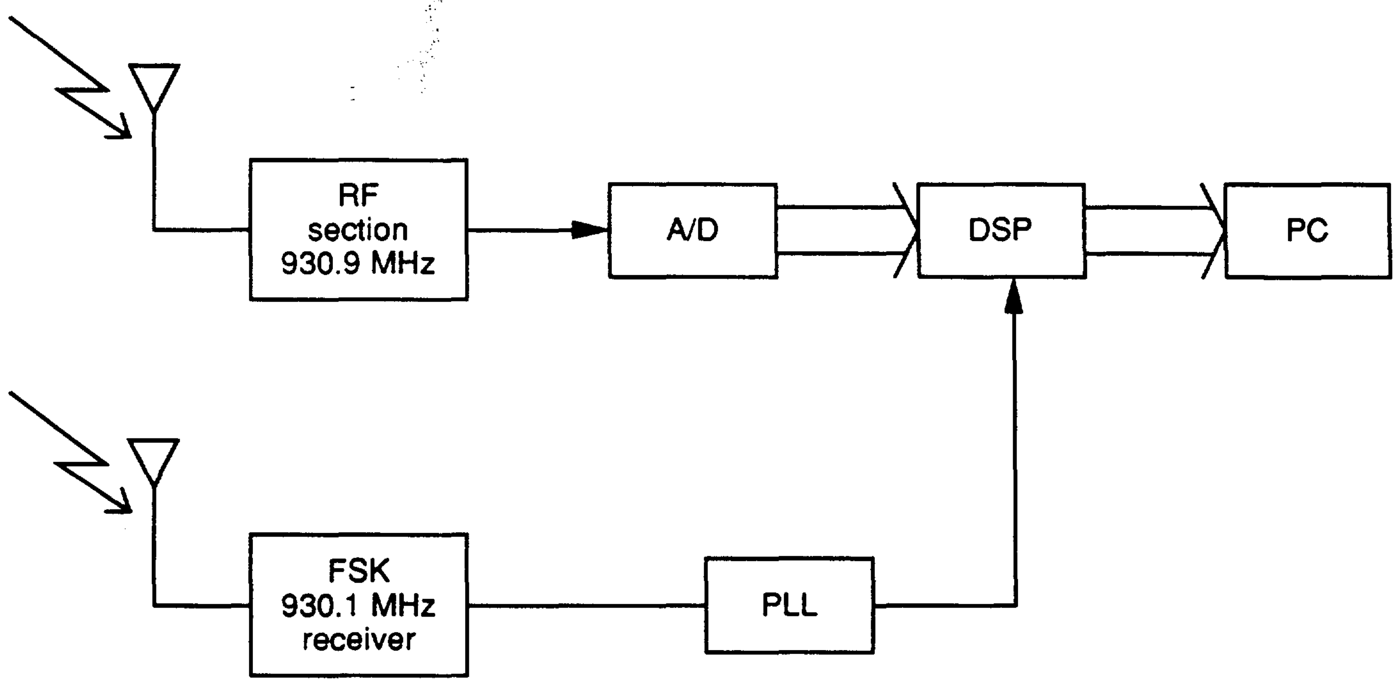


Fig. E-13 Receiver setup for field tests

TAB F

Appendix F

Frequency Selective Fading

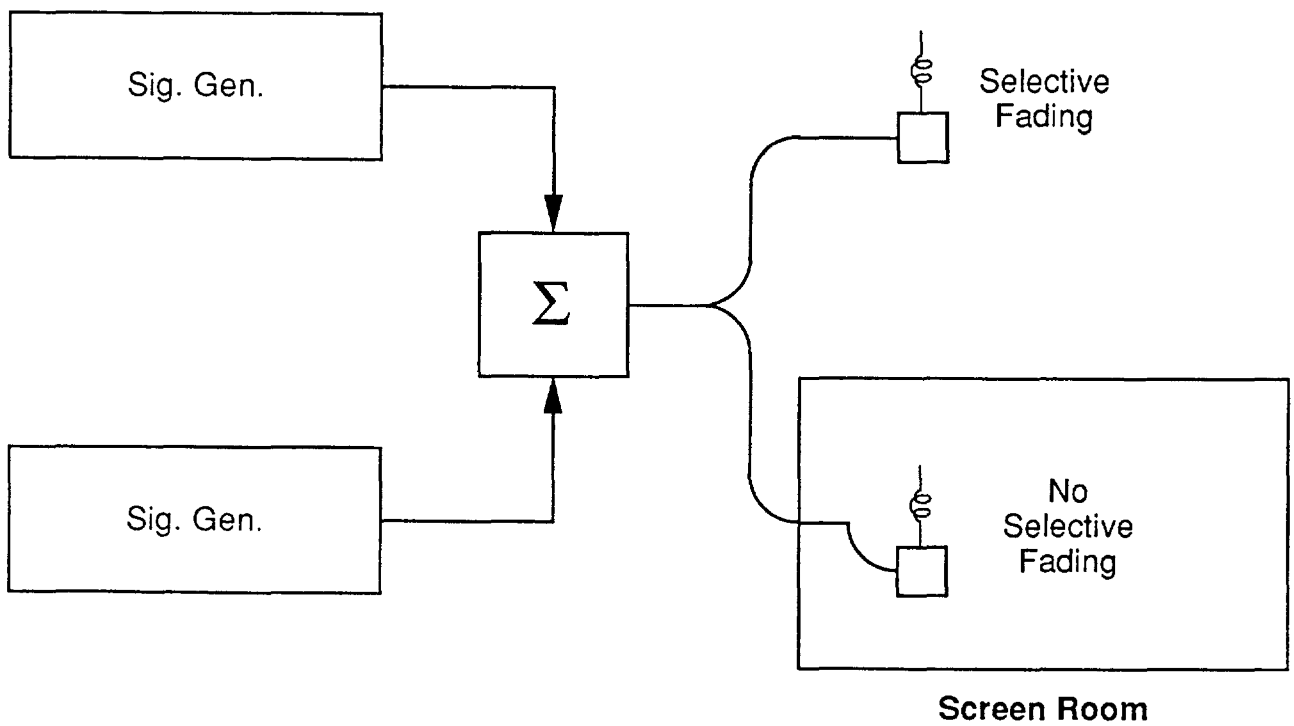
Abstract: Leakage radiation of component carrier signals (non-conducted radiation) can account for the selective fading within the multicarrier signal that was observed during various Oxford, Mississippi experiments. The power radiated over the leakage paths need not be large -- it only needs to be comparable (within a few dB) to a flat faded composite signal radiated by the antenna to result in the 20 dB differential fading observed. Additional tests to confirm the model postulated are presented.

Conclusion: Eliminating leakage of individual carriers to the vicinity of the receiver, located in the lab screen room, eliminated selective fading. This would indicate that leakage path radiation is the cause of the selective fading observed during the June 1992 high power tests. This conclusion could be confirmed by obtaining a linear amplifier to amplify the composite signal and by improving the shielding of the each of the composite carriers prior to combining.

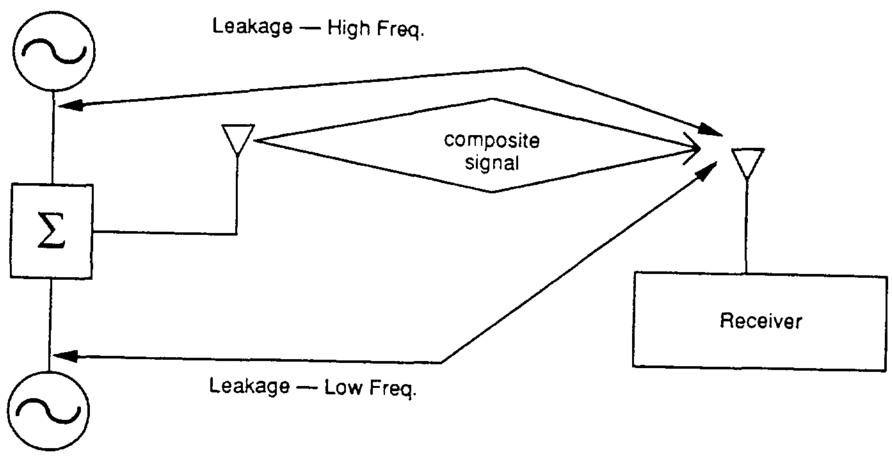
Background: During both the June 1992 high power tests and subsequent low power (laboratory) tests, differential fading of component carriers in excess of 20 dB was observed within a non-simulcast multicarrier signal. This selective fading cannot be caused by multipath delay -- the multicarrier composite signal spans less than 30 kHz and 20 dB of differential fading across this entire band would require over 4 kilometers of difference in propagation path lengths. Since the selective fading was most obvious within the lab/transmitter building, where path lengths were on the order of meters, rather than kilometers, a difference of 4 kilometers was impossible. Furthermore, single carriers in the middle of the composite signal faded -- classic multipath selective fading would give a smooth attenuation envelope across the entire band.

Similar selective fading was never observed across the modulation bandwidth of a modulated single carrier transmitter. Therefore, a number of tests were performed to determine why the multicarrier signals displayed these unique fading characteristics.

Summary of Test Results: A series of tests, described below were performed. Of all these tests, the most revealing were those that used a pair of signal generators and a hybrid as the transmission source. This arrangement exhibited selective fading when all of the equipment was in the same RF environment but the selective fading disappeared when only the composite signal was brought into a screened room and the signal generators and hybrid were left outside.



Discussion: In both the June 1992 high level tests, and the paired signal generator tests, the multicarrier signals were synthesized by generating individual carriers at the final output level and then summing (see diagram below). Therefore, significant levels of each of the component carriers are independently present at the transmitter. Any leakage of these individual carriers (classically called "non-conducted radiation" because the energy is not conducted to, and radiated by, the antenna) will independently propagate and interact with its component in the composite signal.



To have a significant effect at a given location the leakage signal must be comparable in magnitude to its component in the composite signal. This can occur in two ways:

The leakage signal can be strong. This undoubtedly was the case during the June 1992 testing. The combiner was not shielded and had significant sections of coax with the shield removed. The loss through the isolators and the combiner was approximately 10 dB. Therefore, each of the component signals was generated at a level approximately 10 dB above the level that was radiated.

The composite signal can be weak. Both the composite signal and the leakage signal, each traveling its own path to the receiver, independently experiences flat multipath fading. At a given location the composite signal can be severely faded and the leakage signal can be at a high. In this manner even a relatively small leakage signal can be locally comparable to a nominally stronger composite signal.

Test Results:

In earlier testing it was determined that the different carriers in a 4 carrier system experience different fading patterns and that difference in attenuation between carriers could be up to 20 dB at certain spots. Mtel initially suspected that this difference in fading patterns was caused by differences in the carrier frequencies -- *i.e.* "frequency selective fading." Therefore, Mtel also theorized that similar selective fading should be found for different tones in FSK modulation schemes. Consequently, the next step was to investigate fading patterns in an existing FSK channel, such as MTEL's paging channel at 931.9375 MHz and the radio link channel at 930.1 MHz established for experimental purposes in the Oxford area.

The search for frequency selective fading in FSK channels was performed in Lab 234 in Anderson Hall at the University of Mississippi the same place where the results reported on selective fading in the experimental NWN channel were recorded. Again, the receiver antenna was a "pig-tail" antenna designed for 800 - 900 MHz range and the transmitter antennas were at the roof of Anderson Hall. As the first step, MTEL analyzed its own nationwide paging channel using the Anritsu 2601B spectrum analyzer. Despite an extensive effort, Mtel could not detect any difference in a fading pattern for the two frequencies (9 Khz apart) which exist in the signal. A typical diagram that was obtained is given in Fig. F-1. This diagram was obtained during the preamble for 1200 baud paging. It is obvious that the signal changes frequencies regularly during the sweep of the spectrum analyzer. These two frequencies have distinct envelopes which correspond to the transfer function of the instrument's filter. The crucial information is that the peaks of these two envelopes are always nearly level, regardless of the antenna position, *i.e.* there is no detectable selective fading.

Similar results were obtained through FFT analysis of the signal received on a Glenayre RL900 dual conversion receiver and translated to the 40 to 50 Khz band. FFT was performed with a LeCroy 9400A digital oscilloscope. Figures F-2, shows results obtained for one position of the receiver antenna. It shows five consecutive traces obtained without changing the setup parameters. Obviously, fading varies with time, which accounts for differences in consecutive traces (this is probably the result of small movements of the experimenter or other objects in the vicinity), but there is no evidence that the two peaks (representing the two carrier frequencies) experience any differential fading patterns.

The different fading patterns observed for the multicarrier signal and for the FSK signal prompted Mtel to conduct further lab research for the causes of the selective fading. The lab setup for the experiment is shown in Fig. F-3. The two signal generators were Marconi 2022C with output levels of 13 dBm at a 50 ohm output impedance. The hybrid was produced and tuned to 930.9 Mhz by

Decibel Product Inc. The transmitting antenna was a pigtail antenna for the 830 - 960 Mhz region. The receiver antenna was placed in the next room on the same floor.

Figures F-4, F-5, and F-6 show the signal spectrum obtained by combining two carriers 3 Khz apart (nominally) for three different antenna positions. In Fig. F-4, the amplitudes of the carriers are approximately equal; in Fig. F-5 the higher frequency carrier is weaker by 18.28 dB and in Fig. F-6 it is stronger by 25.95 dB. Obviously, quite dramatic differences in fading were observed. It should be noted that antenna positions were deliberately chosen to emphasize the differences in fading. Typical differences are much smaller.

The next experiment had the purpose of establishing if the selective fading would occur for carriers with frequencies as close as possible. Mtel set the frequency difference between the carriers to approximately 120 Hz. Figures F-7, F-8, F-9, and F-10 show the signal spectrums at four different antenna positions. In Fig. F-7 two carriers show approximately the same signal levels. In Fig. F-8 the higher frequency carrier has a 16.96 dB lower level than the lower frequency carrier, and in Fig. F-9 the situation is reversed with a 24.43 dB difference. In Fig. F-10 three traces are plotted consecutively, showing variation in time of the pattern of selective fading.

Mtel also plotted samples of selective fading when both carriers are FM modulated by a sinusoidal 1 Khz signal with a maximum frequency deviation of 6 Khz and a frequency separation of 20 Khz between the carriers. A typical spectrum of the combined signals is shown in Fig. F-11. Each carrier in this figure has signal spectrum with a number of peaks (approximately 20 of them) separated by 1 Khz. For different positions of the receiver antenna the plots shown in Figs. F-12 and F-13 were obtained. It is obvious that different carriers experience different fading, but the frequency components in the spectrum of each particular carrier have equal fading.

As a result, Mtel concluded that the selective fading is not based on frequency selection, but on some other differences in the electromagnetic fields coming from different signal generators. Accordingly, investigation was concentrated on the effects of electromagnetic radiation leaking from signal generators and hybrid circuitry directly (not radiated by the antenna). This radiation is usually dubbed "non-conducted" because the energy is not conducted to the antenna, but rather is radiated directly from the transmitter circuitry.

The antenna was disconnected and a signal level in the next room was accordingly reduced by approximately 20 dB. Under these circumstances, it was much simpler to find strong selective fading (large differences in signal level between carriers) than in earlier experiments. This finding suggests that the selective fading is due to the combination of antenna radiation and radiation leaking from independent signal sources, which results in distinct fading patterns for each carrier.

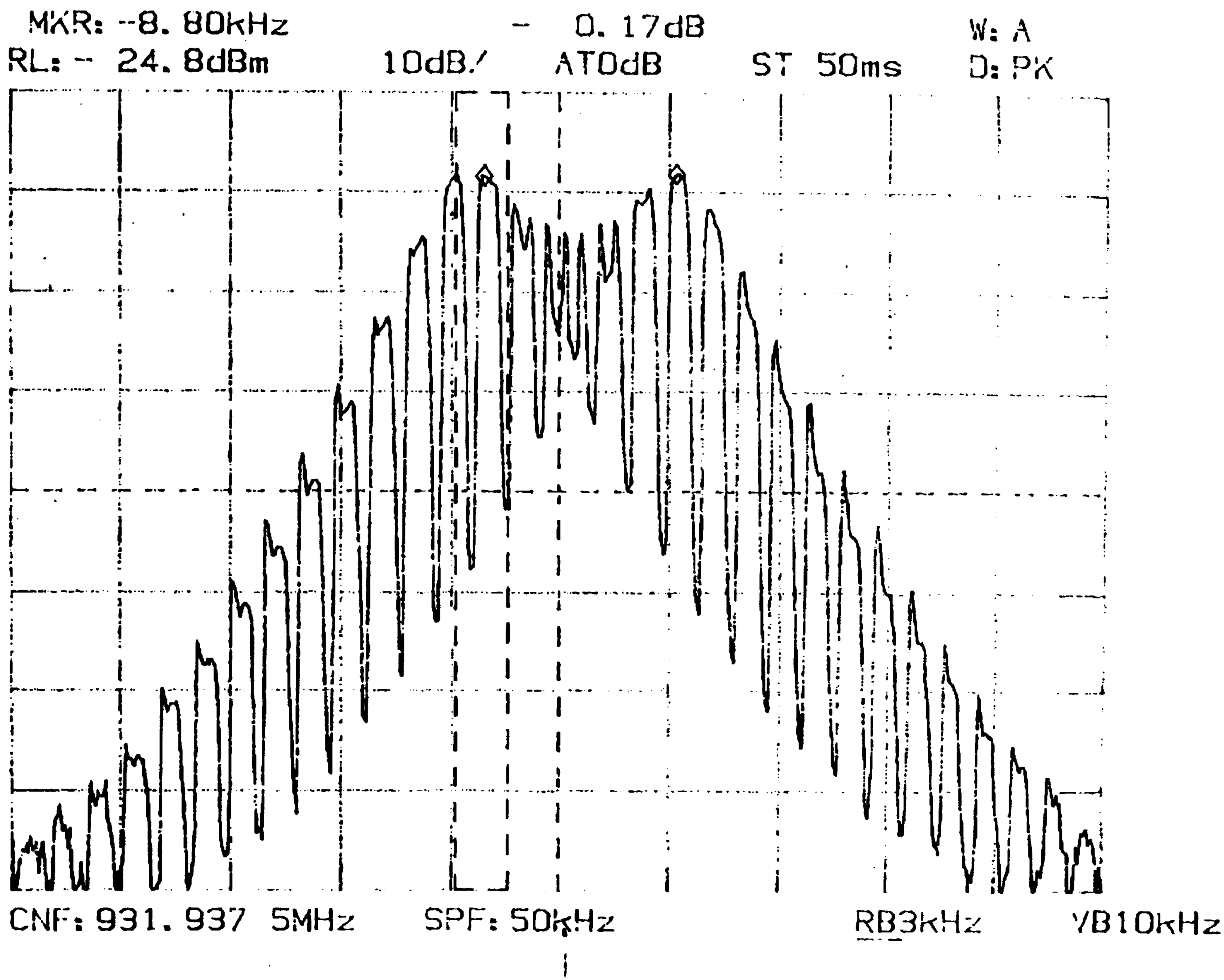
The last experiment was devised to separate fields coming from the antenna and those leaking from signal generators. This was achieved by locating the signal generators outside the screen room and extending the transmitter antenna into the screen room, where the receiver antenna and experimenter were located. It was not possible to detect selective fading for stationary conditions. If something moves in the screen room, however, selective fading may be indicated, but this is an artifact of the spectrum analyzer operation: the sweep of the spectrum analyzer is slow for narrow bandwidth analysis and the flat fading changes during the sweep across carriers. It is interesting to note that fading valleys nearly 70 dB deep were measured without substantial selective fading.

These experiments prove that in the lab environment selective fading is caused by the interference of electromagnetic fields coming from an antenna and fields coming from separate signal sources. There is a strong probability that the same is true for field tests. Basic arguments for this expectation are:

- Fading valleys of 30 dB or even 40 dB were easy to locate at any distance from the transmitter. If the leaking signal is of the same order of magnitude as the faded signal, it will distort the fading valley pattern for different carriers, causing selective fading.

- In earlier Mtel field experiments very little effort was made to prevent electromagnetic radiation leakage directly from the transmitters. In particular, the source of such radiation could be open wires on T couplers used to combine these four carriers.

Since selective fading can complicate the design of the receiver, affecting AGC design and the decision threshold setup, it should be eliminated by a suitable transmitter design. In the case of a composite signal amplified by a linear amplifier, the leakage (non-conducted) energy should not be a problem. If carriers are combined after RF amplification, as in our experiments, special care must be taken to keep the leakage radiation suppressed. This can be achieved by shielding.



MKR: -8. 80kHz
- 0. 17dB
W: A
RL: - 24. 8dBm
10dB/
ATOdB
ST 50ms
D: PK
CNF: 931. 937 5MHz
SPF: 50kHz
RB3kHz
VB10kHz

Fig. F-1

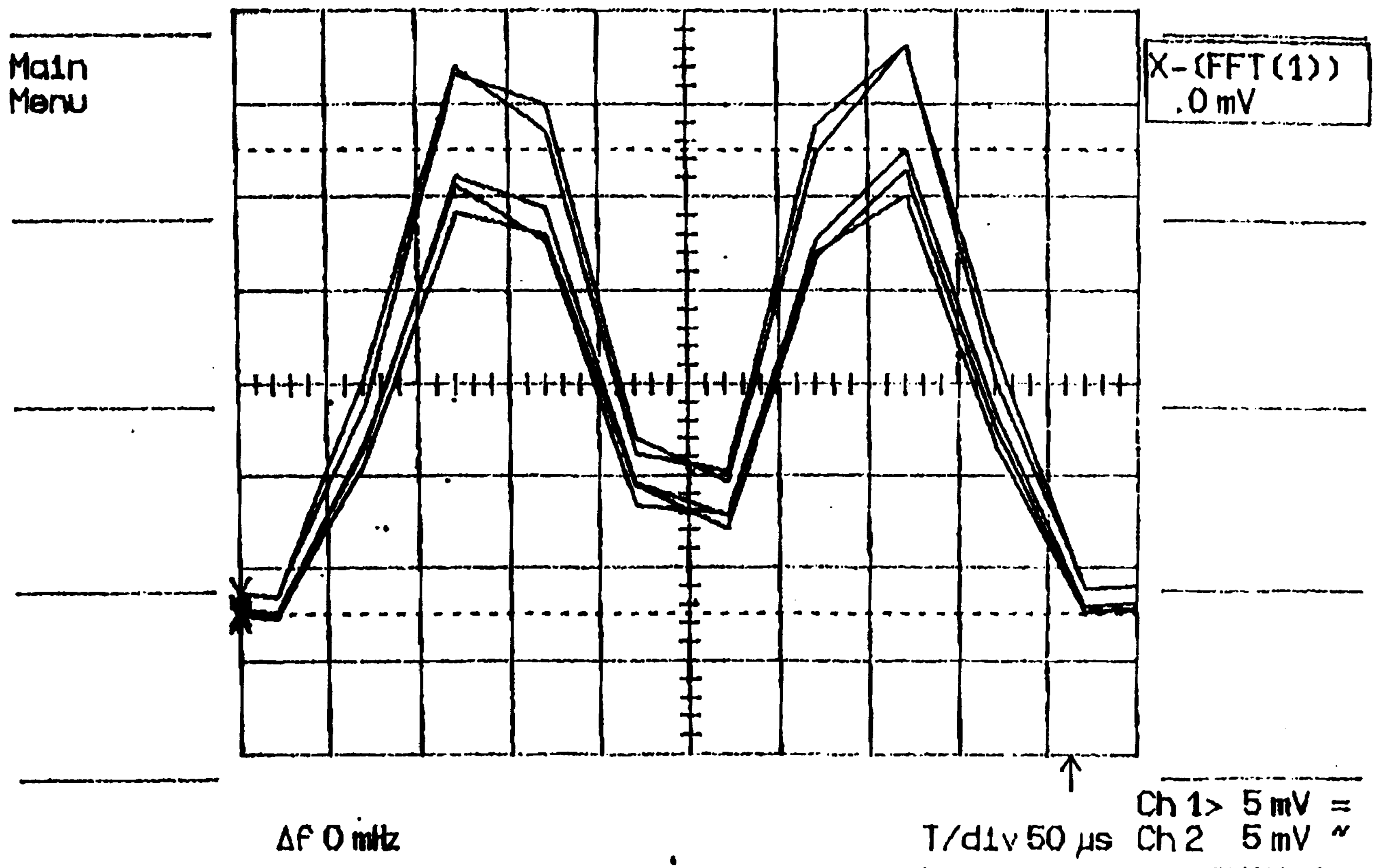

Main
Menu
X-(FFT(1))
.0 mV
Δf 0 mHz
Ch 1> 5 mV =
T/div 50 μs Ch 2 5 mV ~
Trig 1.64 div - CHAN 2 =

Fig. F-2

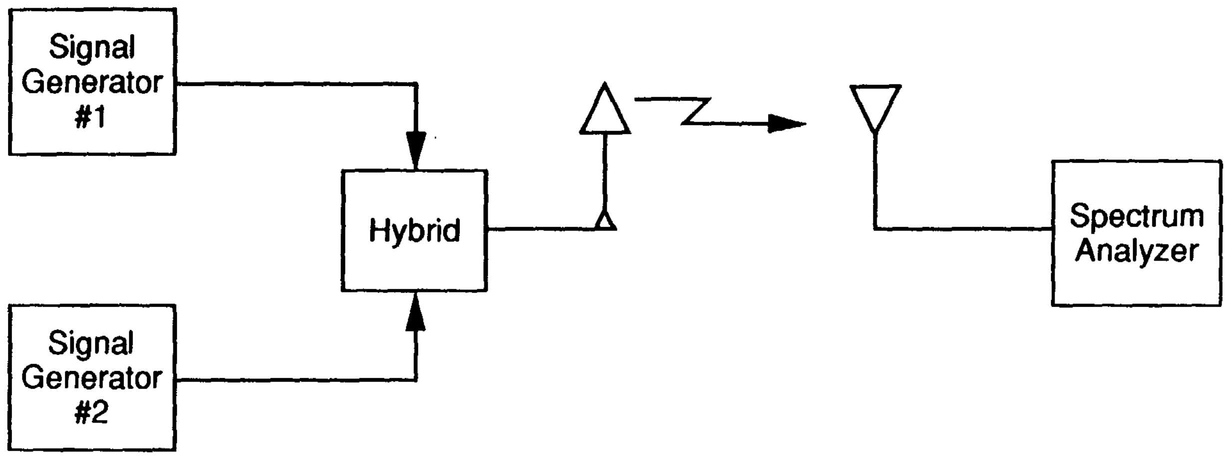

Signal Generator #1
Signal Generator #2
Hybrid
Spectrum Analyzer

Fig. F-3

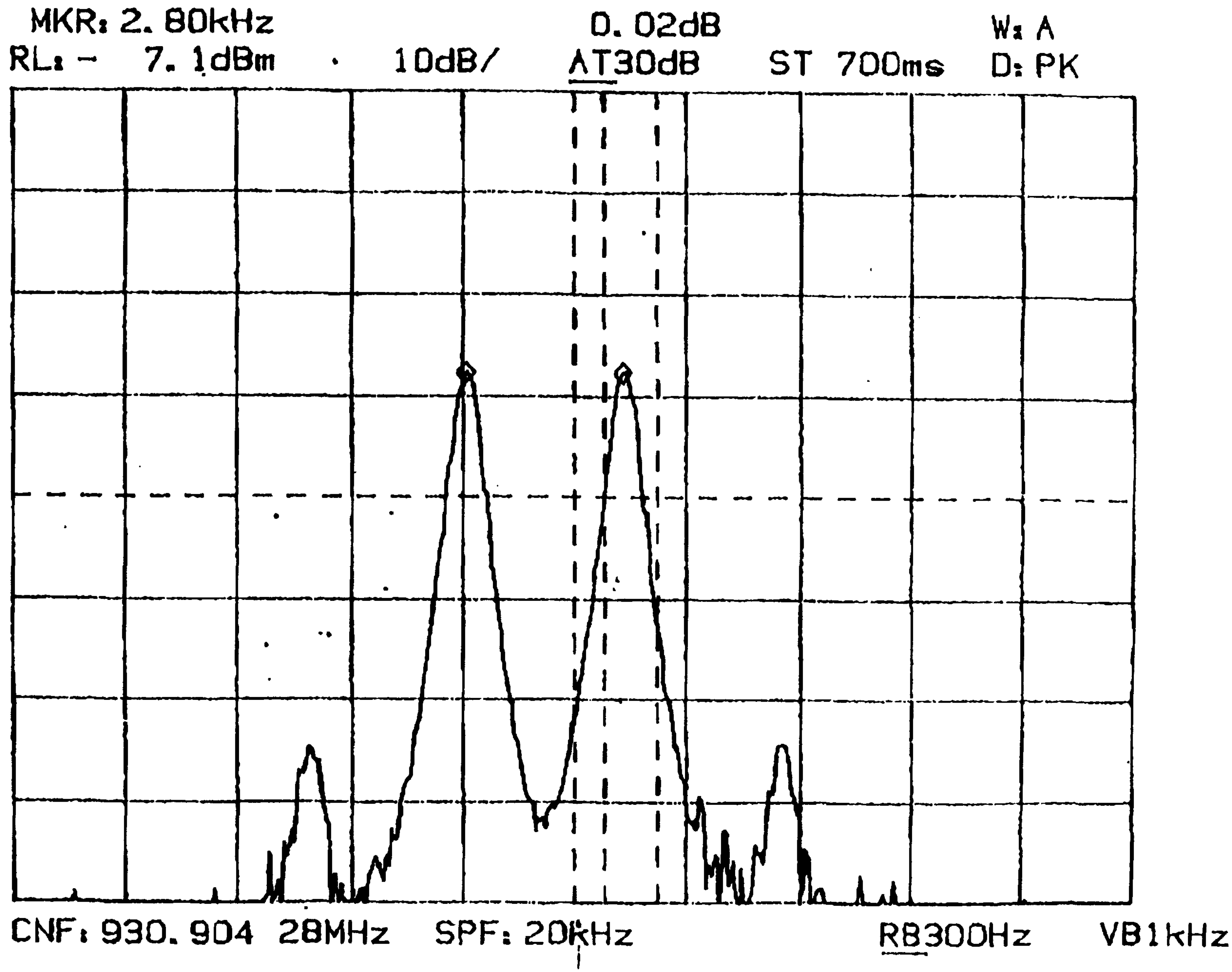

MKR: 2.80kHz
RL: - 7.1dBm
10dB/
0.02dB
AT30dB
ST 700ms
W: A
D: PK
CNF: 930.904 28MHz
SPF: 20kHz
RB300Hz
VB1kHz

Fig. F-4

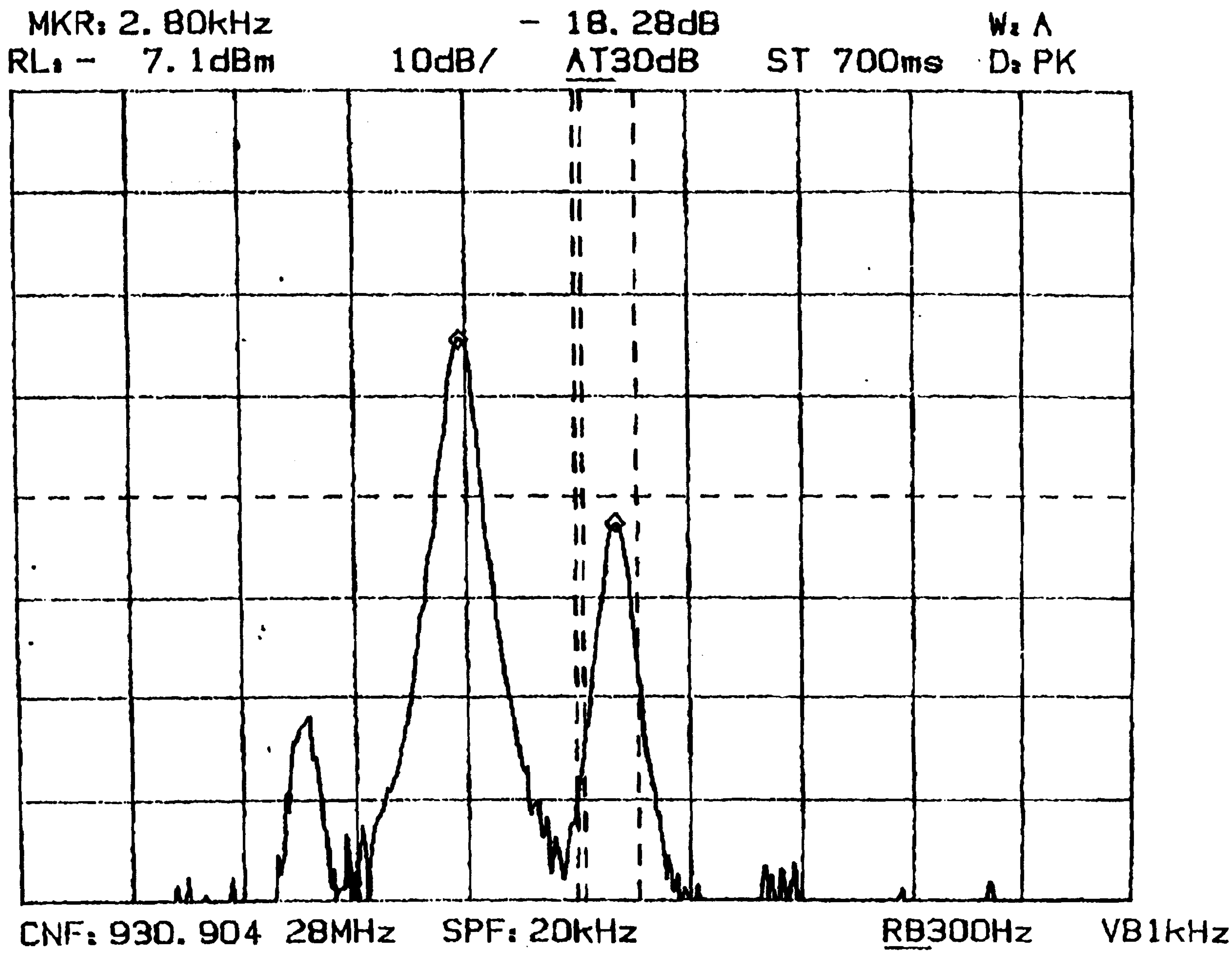
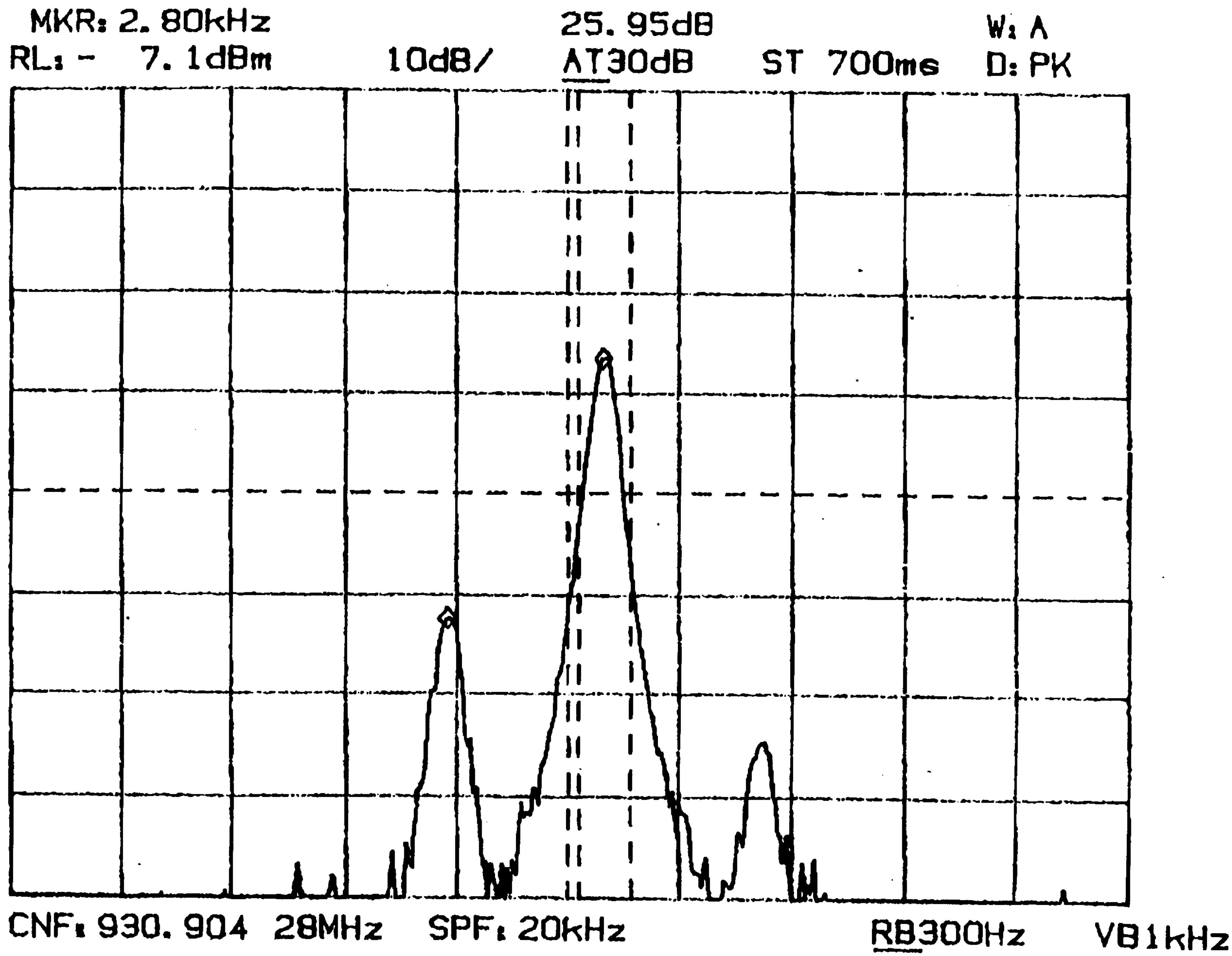

MKR: 2. 80kHz
- 18. 28dB
W: A
RL: - 7. 1dBm
10dB/
AT30dB
ST 700ms
D: PK
CNF: 930. 904 28MHz
SPF: 20kHz
RB300Hz
VB1kHz

Fig. F-5



MKR: 2.80kHz
25.95dB
W: A
RL: - 7.1dBm
10dB/
AT30dB
ST 700ms
D: PK
CNF: 930.904 28MHz
SPF: 20kHz
RB300Hz
VB1kHz

Fig. F-6

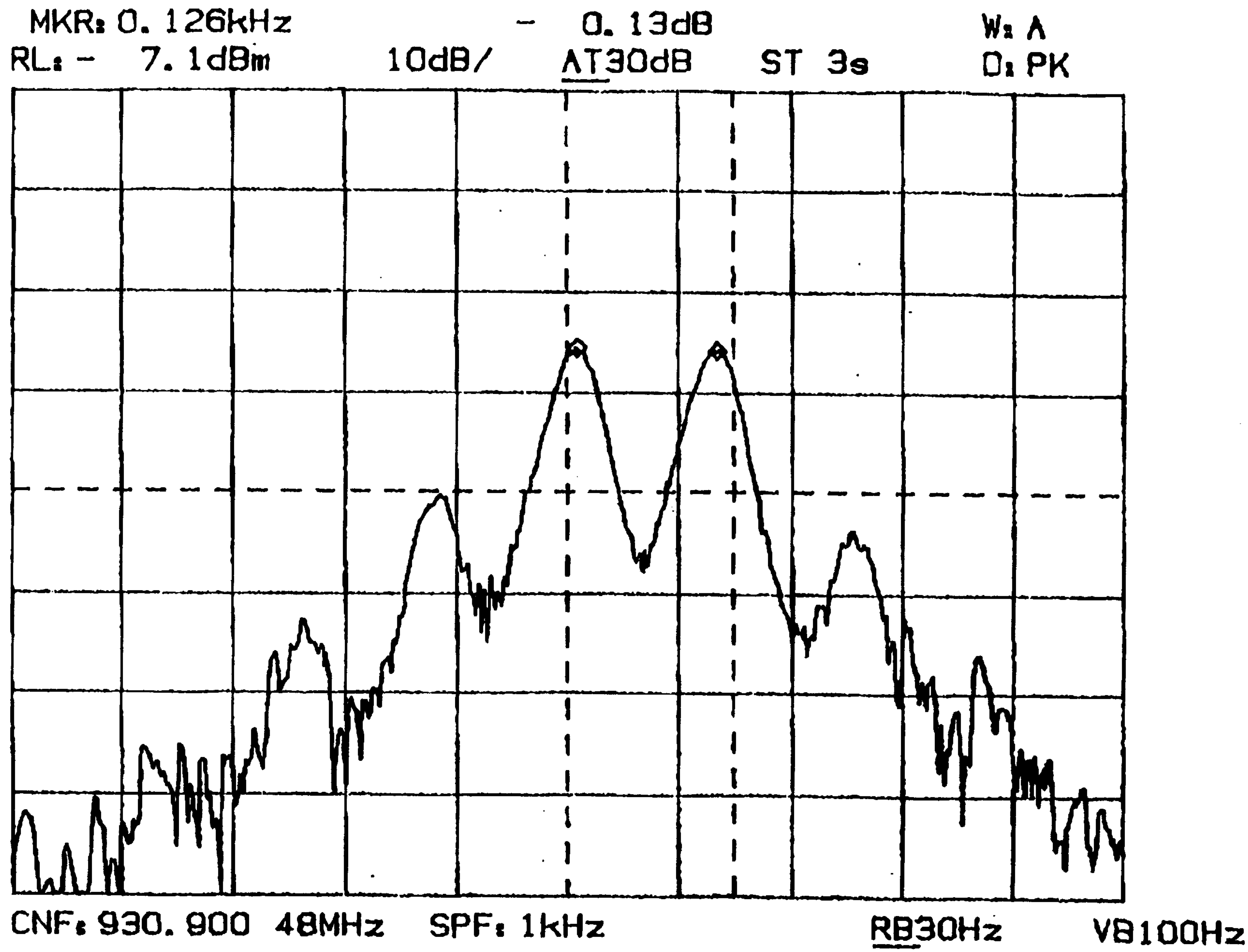

MKR: 0.126kHz
- 0.13dB
W: A
RL: - 7.1dBm
10dB/
AT30dB
ST 3s
D: PK
CNF: 930.900 48MHz
SPF: 1kHz
RB30Hz
VB100Hz

Fig. F-7

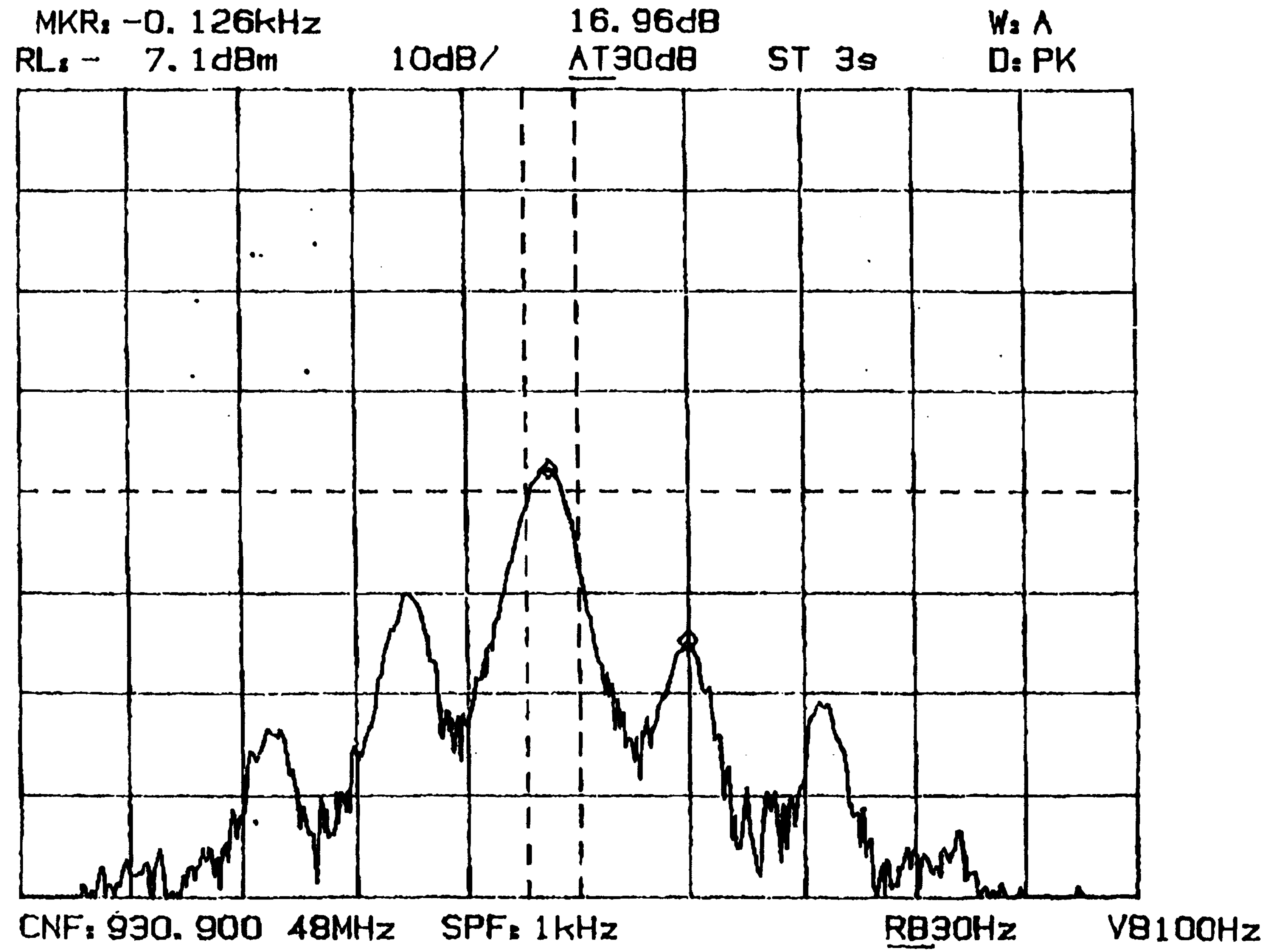

MKR: -0. 126kHz
16. 96dB
W: A
RL: - 7. 1dBm
10dB/
AT30dB
ST 3s
D: PK
CNF: 930. 900 48MHz
SPF: 1kHz
RB30Hz
VB100Hz

Fig. F-8